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FREE-FALL DOWNFLOW OBSERVED IN He I 1083.0 NANOMETERS AND Hβ

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ABSTRACT

In a short time sequence of simultaneously observed slit spectra of He I 1083.0 nm and Hβ we find the signature of material flowing toward the solar surface with up to 42 km s^{-1}, in addition to material which is almost at rest. The constant acceleration of the moving material is about 200 m s^{-2}. These multiple velocities occur in a small region of about 5″ in a plage region. We observe a highly dynamical phenomenon which lasts a few minutes. The duration and constant acceleration suggest free fall of matter unobstructed by magnetic structures or along vertical field lines.

Subject headings: Sun: atmospheric motions — Sun: chromosphere — Sun: infrared

1. INTRODUCTION

The He I 1083.0 nm line provides a tool to probe the upper solar chromosphere (Avrett et al. 1994). Its height of formation has been determined observationally to be at about 2000 km above $\tau_{500\ \mathrm{nm}} = 1$ (Schmidt et al. 1995). The excitation of the line is partially due to photoionization from EUV radiation and to collisional excitation in regions with electron temperatures higher than 20,000 K (Athay 1965; Andretta & Jones 1997). The interplay of those processes is difficult to determine and is still a matter of much debate. While the He I 1083 line observed in spectroheliograms or narrowband filter images clearly reflects the structure of the underlying chromosphere, it also reflects coronal conditions such as coronal holes. The relationship between intensity and velocity structures visible in the He line and similar structures observed in the photosphere and corona has not been studied extensively, at least not with the required spectral and temporal resolution given the dynamics that the He 1083 line exhibits.

New insights into the velocity structure of the transition region were obtained in the last few years by means of the High Resolution Telescope and Spectrograph (HRTS; Bartoe & Brueckner 1975). The spectral lines observed in emission in the UV often show a complex structure, which is interpreted as the signature of several distinct flows occurring within a field of view of about 1″ × 1″ (Kjeldseth-Moe et al. 1988, 1993, 1994; Brekke et al. 1990, 1991, 1992). How these flows connect to the structures in the lower layers of the solar atmosphere, i.e., in the chromosphere and photosphere, is essentially unknown.

In this paper we present the first observation of such multiple flows seen in He I 1083.0 nm and in the red wing of Hβ. We studied the time development of this flow in an observation lasting a few minutes.

2. OBSERVATIONS

The spectra were obtained on 1995 July 9, using the echelle spectrograph of the German Vacuum Tower Telescope (VTT) on Tenerife, Spain and have been reported on preliminarily in Muglach et al. (1997). Two large-format (1024^2 pixel) CCD cameras were used in 4 × 2 binning mode to record He I 1083.0 nm and Hβ 486.1 nm lines simultaneously, with a spatial resolution of 0″.183 pixel^{-1} and a spectral resolution of 13.5 and 5.9 mÅ pixel^{-1} for the helium and the hydrogen line, respectively. The He and H lines were observed in the 20th and 46th spectral order, respectively, and order selection was made with suitable interference filters, mounted in front of the CCD cameras. The raw data were corrected for dark current and for gain, using a gain table obtained from spectra of the quiet Sun, with the solar image rapidly moving across the spectrograph slit, in order to remove spatial structure. The spatial resolution achieved can be estimated from the smallest recognizable structure of the spectra (see, e.g., Fig. 2 below) and is about 1″.

The projected slit of the spectrograph (having a width of 100 μm, corresponding to 0″.46) covered 94″ on the solar disk and was placed upon a region of active plage near disk center (cos $\theta = 0.97$). The region also contained a sunspot as can be seen in simultaneous (video) slit-jaw images taken in white light and Ca II K (see Figs. 1 and 2).

A series of 16 spectra was recorded at intervals of 15 s, and the exposure time for both lines was 10 s. We used the correlation tracker of the VTT (Schmidt & Kentischer 1995) to stabilize the image to a fraction of an arcsecond, well below the slit width, and to take out solar rotation. The precision of the guiding ensures that the time sequence is not corrupted by motions of the image relative to the spectrograph slit.

3. RESULTS

Figure 3 shows the time sequence ($\Delta t = 30$ s) of that part of the spectra in which multiple velocities are present. The central part of Hβ (*left column*) and He I 1083.0 (*right column*) show a broadening of the profiles at the beginning of the time sequence. Later the helium line splits into two separated profiles (e.g., No. 9), while the hydrogen line becomes more and more asymmetric.

Two minutes after the start of the observations (see Fig.

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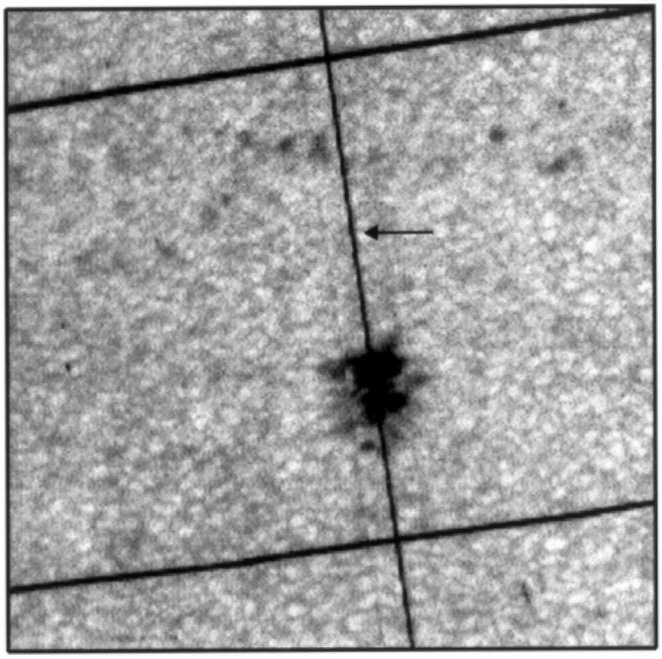

FIG. 1.—Slit-jaw video image of the observed region in white light. The vertical line is the spectrograph slit, the two horizontal ones are hairs. The arrow indicates the position where the multiple velocities occur.

4) we get two clearly separated helium profiles (e.g., in No. 9 they are 0.119 nm apart, which corresponds to a downflow of 32.5 km s^{-1}). After 3.5 minutes the moving feature is not discernible because the Doppler shift has reached the neighboring terrestrial H_2O line. Whether the dynamic process on the Sun has come to an end cannot be determined, since beyond that line the spectral field of view is limited by the CCD.

We determined the line-of-sight velocities from a polynomial fit of the central part of the helium line, using the position of a spatially and temporally averaged quiet-Sun profile (which was observed immediately afterwards at the same position on the disk) as a reference. Only those profiles were fitted where one can clearly discern two separate helium profiles. The central helium component is redshifted by a few km s^{-1} in most positions compared to the quiet Sun. The velocity of the second feature in time is plotted in Figure 5 for selected positions along the slit (as indicated in the figure caption). We get velocities as high as 42 km s^{-1}.

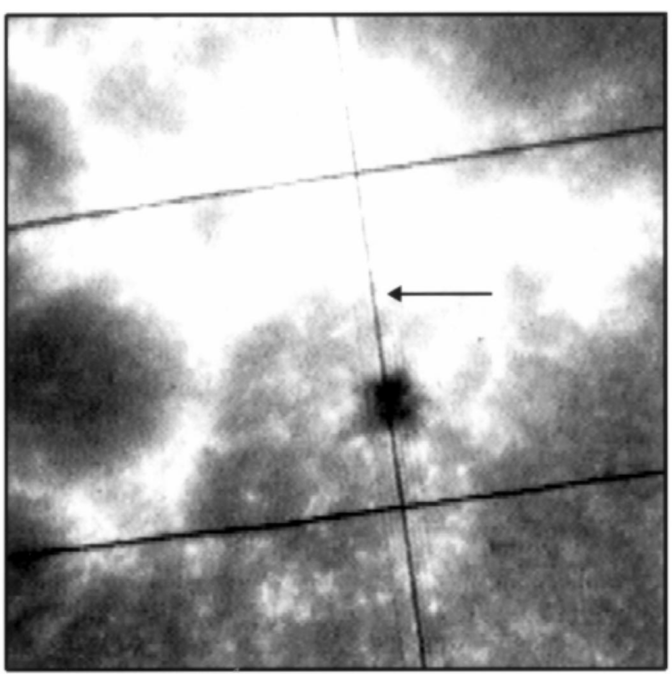

FIG. 2.—Same as Fig. 1, but taken in Ca II K

The Hβ line signal does not allow for a determination of a velocity magnitude due to the width of the line. It does contain, however, two important pieces of information for the interpretation of the process observed in the He line:

1. The Hβ line is formed at lower levels of the solar atmosphere; hence, we conclude that we are observing an actual flow of material that extends over a considerable height distance in the atmosphere.
2. The onset of the downflow event is as far as we can determine instantaneous in the two lines, suggesting that a whole column in the solar atmosphere is moving downward rather than a parcel of matter falling down from the corona.

We also note that Hβ shows a "moustache" phenomenon within the field of view represented in Figure 3. The moustache is the pair of bright streaks to the left and right of the Hβ line center, located in the upper part of each subimage of Figure 3. That signature is actually caused by a weakening and narrowing of the line (see Fig. 6). However, neither the strength of the moustache nor its asymmetry show any significant change during the observed downflow event. We therefore conclude that this feature is unrelated.

The downflow event is slightly off disk-center at a heliographic angle, θ, of 14°, and our measurements provide the line-of-sight component of the material motion. It is immediately clear from simple geometric arguments that the observed motion has to be virtually vertical (see also Fig. 7): if the observed flow were the line-of-sight component of a horizontal motion, the horizontal speed would have to be $v_h = v_{\rm los} \sin \theta$, corresponding to a maximum velocity of about 240 km s^{-1}. Such a horizontal motion would move the compact feature quickly along the spectrograph slit or at some angle to it. In the former case, the motion would be clearly visible, and in the latter case, the feature would move off the slit and disappear from the data within seconds.

4. DISCUSSION AND CONCLUSION

Observations with the HRTS indicate emission lines of up to five different components within the same resolution element of $1'' \times 1''$ (Brekke et al. 1991). Usually one component is at or close to rest (as in our observation); most of the others are redshifted, ranging from 20 up to 180 km s^{-1} (Brekke et al. 1992). The data from HRTS reveal that the multiple velocities occur throughout the transition region (using a number of different emission lines) and that they are not restricted to areas above sunspots or active regions. The flows are even observed in chromospheric lines like O I at 130.1 nm.

Recently, others have reported high-velocity events in the He I 1083 line in conjunction with coordinating *SOHO* EUV and groundbased observations (Andretta et al. 1998). From early analysis of snapshots from these data sets, it is apparent that high-speed events are quite common in the He line and that these events have counterparts in the corona. However, these observations have been taken at large heliocentric angles, which compromises a straightfor-

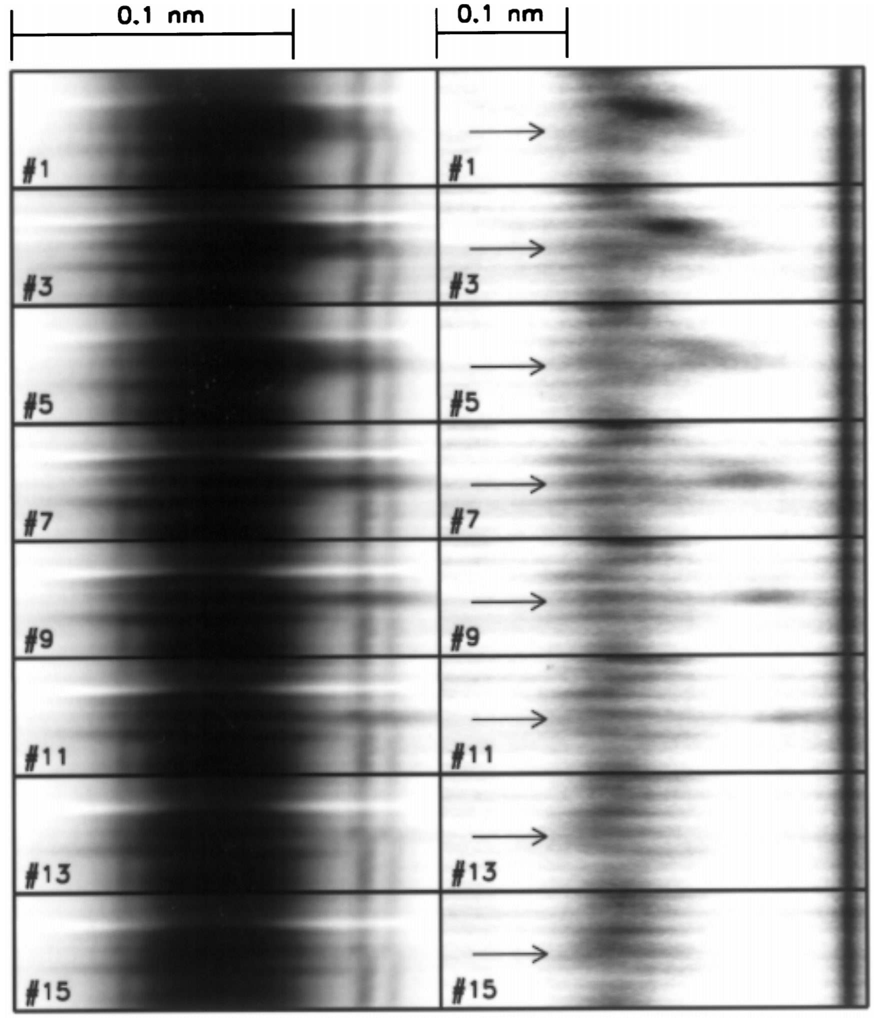

FIG. 3.—Time sequence of images of Hβ (*left*) and He I 1083.0 nm (*right*): the horizontal and vertical coordinates correspond to wavelength and spatial coordinate along the slit, respectively. Each subimage covers 20″ centered around the arrows shown in Figs. 1 and 2. The wavelength scales are given by the bars on top of the figure, their widths correspond to 0.1 nm (equivalent to 27.7 km s^{-1} for the He 1083.0 and 61.7 km s^{-1} for Hβ). The time between two subimages is 30 s. The arrows indicate the spatial position where cuts have been carried out and shown in Figure 4.

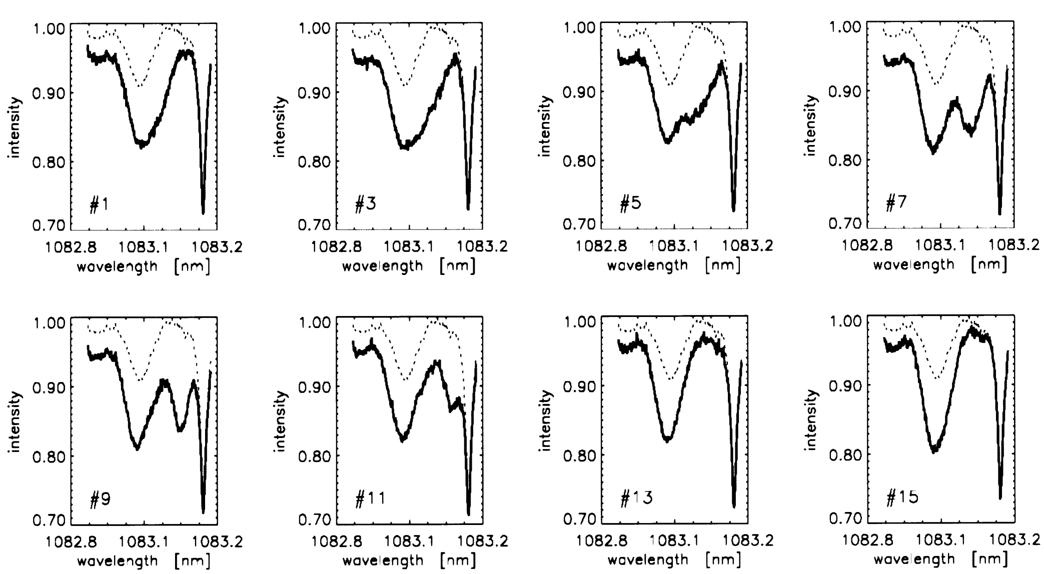

FIG. 4.—Individual profiles of the helium lines of Fig. 3. The solid lines represent the observed helium profiles in the "multiple velocity region," the dotted line the ones from a region without large flows (*dotted line*).

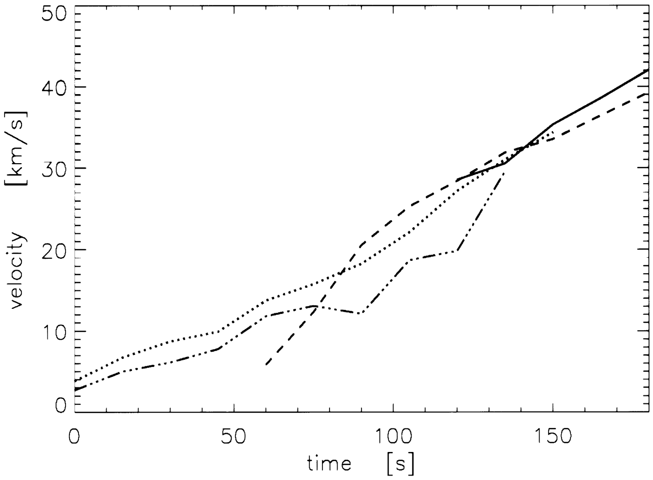

FIG. 5.—Velocities derived from the moving component of He I 1083.0 nm (in km s^{-1}) vs. time (in s) for various positions along the slit: $x = 42''.86$ (*solid*), $x = 44''.70$ (*dashed*), $x = 46''.53$ (*dotted*), $x = 48''.18$ (*dashed-dotted*).

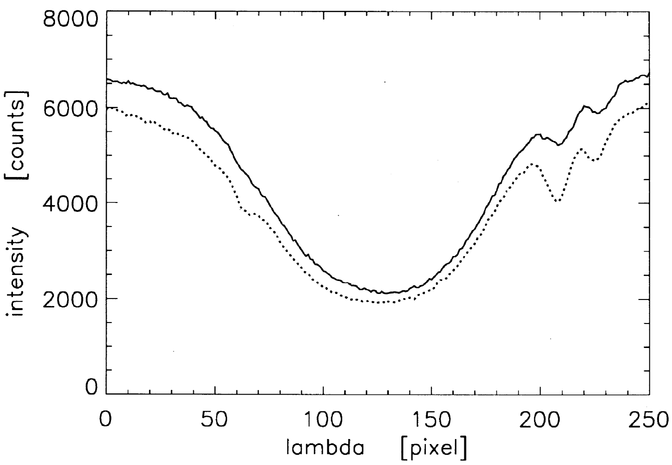

FIG. 6.—Profiles of the Hβ line measured in a quiet part of one of the spectrograms (*dotted*) and through the "moustache" (*full line*): inside the "moustache" the line is both weaker and narrower.

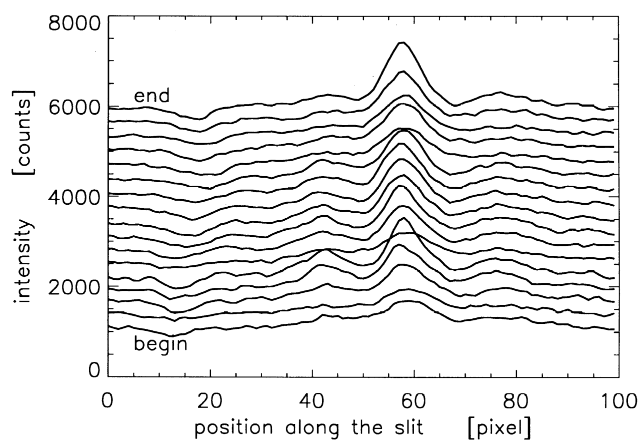

FIG. 7.—Intensity in the blue wing of the Hβ line as a function of time. Each curve is shifted in intensity. The bright feature corresponds to the "moustache" located near the downflow region. The increased brightness corresponds mostly to the narrowing of the line profile (cf. Fig. 5). The graphs shows the fixed location of the feature along the slit and also the invariability in time during the downflow event. Profile-to-profile differences can be addressed to varying seeing.

ward interpretation of the flows involved as pure up- or downflows.

From the time evolution of the velocities reported here (see Fig. 5) we estimate the acceleration of the moving material to be about 200 m s^{-2}. Note that $g_\odot$ is 274 m s^{-2}. The acceleration is constant during the observed time of the downdraft. This is a surprising result in view of conventional attempts to explain the downdrafts observed in the transition region and in the corona. Pneuman & Kopp (1978) and Athay & Holzer (1982) tried to explain the redshifts as the fallout of spicule material. We conclude that the onset of the downdraft at the same time in Hβ and He rules out this scenario. Boris & Mariska (1982), McClymont & Craig (1987), and Mariska (1988) generated models of siphon flows (Meyer & Schmidt 1968) in coronal loops whose downward components would then be observed in the transition region. We do not see how the magnitude and the shape of the velocity signal can be reproduced by the siphon models discussed. More recently, Hansteen (1993) identified the net redshift caused by downward propagating acoustic waves generated in the corona as a result of nanoflares. We stress that the phenomenon observed here is clearly due to an actual mass motion. The observation presented here cannot be explained by any of these processes given the duration, magnitude, and acceleration profile of the event.

The presence of the mostly undisturbed He line together with the strongly redshifted component implies that the 90 s accelerated downflow occurs below the layer of nonmoving gas. Otherwise the falling material would have to cross that layer and thereby disturb or even destroy the unshifted He line, thus leading to the more common high-velocity events reported in the literature. Since the He I 1083 line is optically thin, the presence of multiple flows can be interpreted as follows: the unshifted component which stays at rest throughout the observation tracks the well-known He shell at an altitude of about 2000 km above $\tau = 1$. The moving component tracks a parcel of matter in free fall. Assuming that the conditions for the formation of the line in this parcel do not change during the observation (an idealization!), we can deduce the maximum distance that this idealized parcel has fallen during the observation. This distance amounts to ≈ 2200 km (see Fig. 5), which is not unreasonable given the height of the He shell.

We propose that the constant acceleration of a flow observed as low as in the chromosphere might be evidence for the flow connecting down to subsurface layers of magnetic flux tubes where a convective collapse (Parker 1987) efficiently carries down matter by an evacuation of the tube. This explanation is partially supported by the apparent sharpening of the spatial structure with time, though the effect of line formation also comes into play. Future systematic studies of similar events and their location relative to high-resolution imaging of the magnetic structures in the solar atmosphere will have to investigate this explanation further.

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